KiM | Netherlands Institute for Transport Policy Analysis

Driver at the wheel?

Self-driving vehicles and the traffic and transport system of the future

4 scenarios

4 scenarios

Scenarios envision the possible traffic and transport systems of the future and hence highlight the associated advantages and disadvantages.

A car that you must drive yourself? This will perhaps be a hopelessly old-fashioned concept in a few years' time, even if we can hardly imagine such a reality today. A car is a car, with a steering wheel, pedals, gears ... and a driving license required to operate it, yet it was not so long ago that people could not imagine this, either. Or, as legendary carmaker Henry Ford once said: *'If I had asked people what they wanted, they would have said faster horses.'* Faster horses ... those were what people wanted. After all, they had not yet even heard about cars.

Not self-evident

When we look into the future, we automatically do so from our present perspective. And this also applies to transport modes, whether a horse or 'ordinary' car. We do not know of anything better than a car that you must drive yourself; however, this is not as self-evident as it seems. The advent of the self-driving car – a car we no longer need to drive ourselves – can radically change our perception of a transport mode. But how does such a self-driving car actually work? Is the technology already so advanced? And, crucially: do people even want self-driving vehicles?
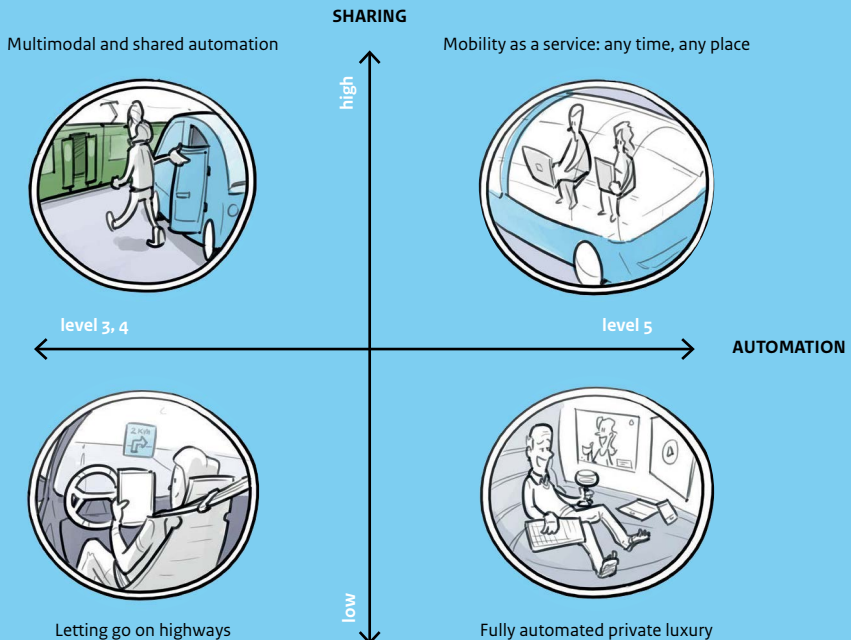
Future scenarios

The transport mode of the future is highly dependent on the answers to these types of questions. We therefore gaze into future from the perspective of various possible future scenarios. Technology is rapidly developing and the 'robot car' may ultimately look very different than we now suppose. And perhaps the self-driving car will also be a self-driving shared car. Such scenarios inspire and assist analysts and policymakers in dealing with uncertainties. Scenarios envision the possible traffic and transport systems of the future and hence highlight the associated advantages and disadvantages. Additionally, they can help us to reason backwards and see how certain developments, events and possible (policy) choices can influence the future in the short- and medium-term.

About this study

In this study, the KiM Netherlands Institute for Transport Policy Analysis presents four different scenarios for future traffic and transport systems involving self-driving vehicles. In addition, we explicitly examine the wider societal effects: how do such systems impact the use of various transport modes, and what are the social, spatial and economic implications?

The scenarios presented in this study are the result of explorative and qualitative research. First, we mapped the key uncertainties, classifying them according to their degree of uncertainty and impact. Hereby, two uncertainties were dominant: the level of automation, and the degree of sharing car ownership and car trips. The scenarios were then reviewed and adjusted during four expert sessions involving specialists from various knowledge organizations, government agencies and private companies. The four scenarios that were ultimately defined are detailed in this paper.

SHARING

high

Multimodal and shared automation

Mobility as a service: any time, any place

level 3, 4

level 5

AUTOMATION

low

Letting go on highways

Fully automated private luxury

Levels of automation

What do we mean exactly by the term self-driving or automated vehicles? The *Society of Automotive Engineers* distinguishes six levels, ranging from 'no automation' (Level 0) to 'full automation' (Level 5). In full automation, the car drives fully automatedly on all roads and in every situation. The driver has become a passenger and does not need to take control of the vehicle in any situation (this is not yet even possible).
The intermediate levels are characterized by an increasing automation. In Levels 1 and 2, the driver closely monitors the surroundings, but in Level 3 the technology (conditional automation) starts to take over. If, in certain environments, such as on highways or in parking garages, the driver is absolutely not needed as 'back-up', we have then reached Level 4 (high automation).

Level	Name	Example
Human driver monitors the driving environment		
0	No automation	Lane Departure Warning
1	Driver assistance	Adaptive Cruise Control
2	Partial automation	Parking Assistance
Automated driving system monitors the driving environment		
3	Conditional automation	Highway Chauffeur
4	High automation	Parking Garage Pilot
5	Full automation	Robot Taxi

Sharing economy

For a large part of the day, a car remains unused, parked, and is thus inefficiently used and part of a large overcapacity. This not only applies to cars, but also many other types of personal possessions, such as tools, a camper or party tent. This unused capacity is the root of the sharing economy, in which online platforms are developed to make sharing possible, often involving financial compensation.

Car sharing is on the rise. In 2014, there were some 5 million car sharers and more than 100,000 shared cars worldwide. These are still marginal figures, but given the steady growth in the number of users and the number of providers of shared cars, they will seemingly gain in importance. Two types of sharing can be distinguished: the sharing of a car and the sharing of a ride in a car (with multiple people travelling in one car at the same time).
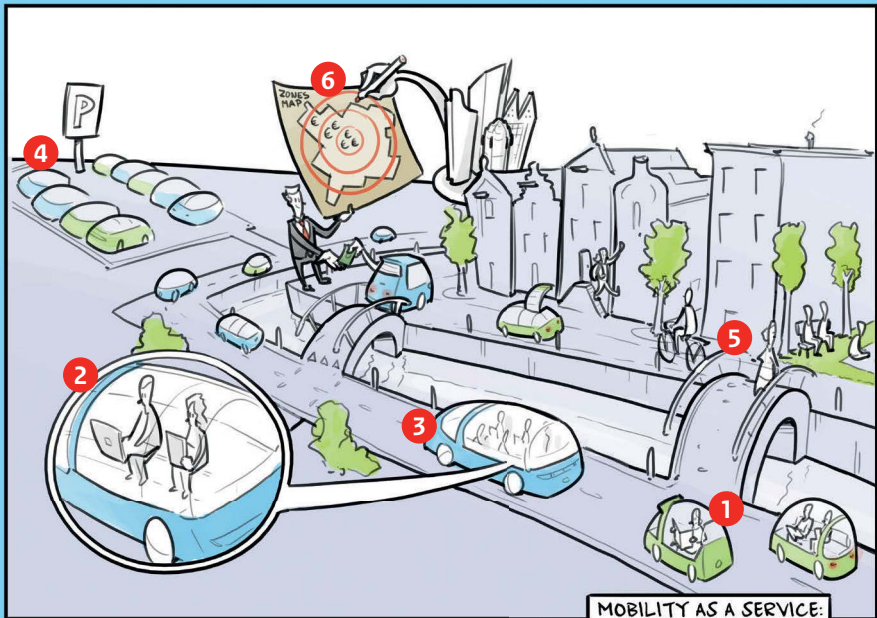
MOBILITY AS A SERVICE: ANY TIME, ANY PLACE

- Door to door travel via automated people movers (1)
- The sharing economy flourishes (car ownership and rides) (2)
- Disappearance of (most) traditional public transportation (3)
- Cars park themselves in parking areas situated on the outskirts of the city (4)
- People opt to walk and cycle whenever possible (5)
- Price/km within the city increases (6)

Scenario 1
Mobility as a service: any time, any place

In the first scenario, the assumption is that the technology is developed to a high level and that consumers are extremely willing to share their transport mode. Mobility has become a service, and self-driving cars are always and everywhere available.

Steering wheel-less through life

During his ride to work, George had all the time in the world to think about the past. At 8:00, the robot bus was on the road, and all George had to do was get on at the agreed place and sit down in his reserved seat. Gosh, he can still remember the days when he actually had to do all of this himself: steer, shift gears and keep his eyes on the road. George can hardly believe it, but once upon a time he used to own his own car: an expensive and unsafe thing that he had to clean and maintain himself. Fortunately, in time he was able to switch to a shared car, which was already a vast improvement. Technology does not stand still, however, and shortly after the first robot cars came on the market, small robot buses followed. These vehicles were fully automated, always knew exactly what routes to follow and never got into road accidents. You could read, work, sleep, play with your kids, while anything else you might need was arranged for you. Before you knew it, you were at your destination, No, George was more than pleased with the robot bus he shared with others. The pleasant background music then stopped and George was brought back to reality. He had reached his destination.

General overview

The car as butler

The auto industry and ICT companies have joined hands and are deeply invested in automation. The technology is highly developed. Cars can independently navigate through traffic. Consumers are positive about this development. The car is a butler that does all the work for you, obligingly driving and delivering you to your destination. The government believes this to be a favorable development from an environmental and road safety standpoint. Policy and regulations are adapted, so that self-driving vehicles have free rein.

In fact we will share everything

Car sharing in the Netherlands began its ascendency in 1990. Following a tentative start, it is now in full flight. Today, some people still own cars, but the majority of people opt to share a car. This makes an enormous difference in costs, and, no less importantly, the liveability of cities is rapidly improving. Sharing makes a key contribution to the sustainable environment, and, for this reason, not only cars but also many trips are shared. One no longer needs to own a car in order to travel with ease.

Large car fleet companies now exist to manage cars and offer travel services. One can choose from a variety of options: cars and small buses are available in all types and sizes. Mobility has become a service, with the market providing something for everyone. Moreover, your personal digital travel assistant arranges everything for you, offering numerous options. On some occasions you may want privacy and hence prefer to pay more to travel alone, while at other times you find it enjoyable to share a ride with others, which also costs less. In addition, driving during peak hours is more expensive than driving during non-peak hours.
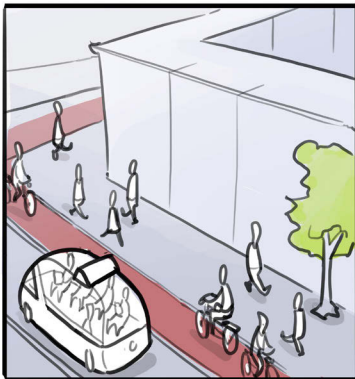
Livable cities

Travel has become incredibly easy, and this can lead to people making extra trips. The government does not want the system to fail due to its own success and is committed to maintaining livable cities. The self-driving car is not allowed to travel everywhere: the city is divided into zones, and those who want to enter the city center must pay more for the privilege. The city must remain green, and the preference remains for livable inner cities in which people cycle and walk.
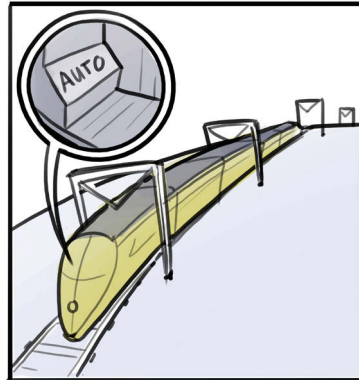
Other transport modes

Farewell to the bus and tram

Local public transport as we knew it in the past – travelling by bus and tram – largely no longer exists. Cars, public transport and taxi have merged. You now travel from door to door via *people movers,* particularly in the city. Concurrently, many people are convinced that a healthy lifestyle is most important and thus opt to walk and cycle whenever possible. This is facilitated by the availability of plenty of bicycle paths and sidewalks in the city.

Self-driving packages in freight transport by road

Goods are delivered by self-driving trucks. Compartments for drivers are no longer necessary. The goods are delivered to the outskirts of the city, where they are transferred and automatically delivered to their final destinations.

Trains still exist for travelling longer distances, and metros operate on busy routes in major cities, but they do not have drivers and are both inexpensive and fast. Moreover, the centrally situated station is easily accessible. Higher fees are used to discourage people from travelling alone by car and undertaking short trips. Hence, the inner city remains accessible and livable.

Societal consequences

Mobility as a service has various effects in areas such as safety, social cohesion, spatial planning, the environment and the economy.

Road safety: 'Look Mom, no hands!'

Because the self-driving car is full of technological innovations, road safety has vastly improved. We are no longer at the mercy of drivers who can easily become distracted in all manner of ways (by talking with a passenger, the navigation system, incoming cell phone calls and messages ...). Even the drivers who hold nothing sacred are relics of the past. Technology has taken over everything and does all the work ('Look Mom, no hands!'). Moreover, other forms of safety have also been considered; hence, the system is protected against hackers. All cyber-attacks fail and consumers therefore have complete trust in the new technology.

Everyone onboard

The self-driving car has new groups of travelers onboard. People with handicaps, such as the blind or visually impaired, children, and senior citizens who can no longer drive present no problems in this *'Mobility as a service'* scenario. People no longer need to walk to bus stops, because the robot car or robot bus picks everyone up at their door or another convenient location.
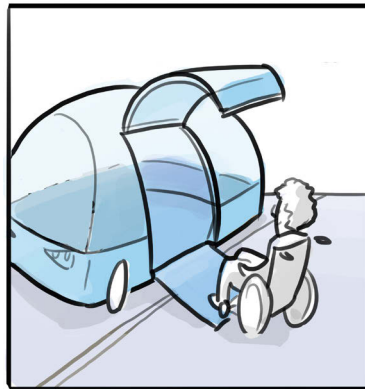

Spatial developments: from pillar to post

An ever-increasing number of people – especially young people – are moving to the city, which is perfectly understandable, as cities have become increasingly attractive. Inner cities are revitalized, offering all types of places (cafés, restaurants and theaters) where people can meet. Because of the ease afforded by self-driving cars and *people movers*, the city can be traversed in all manner of ways, and the city's outlying areas are now easy to

reach. Trips are relatively less expensive on the outskirts of the city than they are in the inner city, and, owing to the easy accessibility, the services offered on the outskirts are flourishing. Cities remain compact however with clearly defined city centers.

The self-driving car has made the countryside more accessible, and this is especially true for people with handicaps, for senior citizens and children, who are now less dependent on others, because self-driving shared cars can transport them anywhere with ease. The automation of freight transport has also further improved the liveability and accessibility of the countryside. Groceries and other packages are automatedly and inexpensively delivered to your door. Due to the scale, large car fleets are situated in and around cities, but in the countryside car sharing also occurs among private individuals ('peer-to-peer').
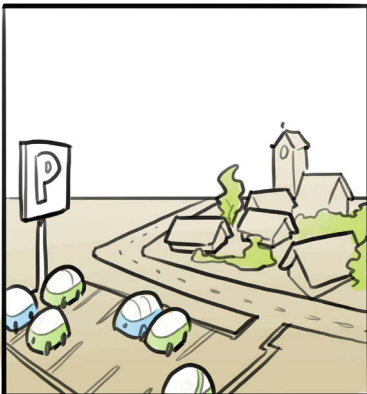

Because increasingly fewer numbers of people own cars, increasingly fewer parking places are required as well. This is also due to the fact that self-driving cars and self-driving minivans are used intensively. In past, during the age of private ownership, cars primarily demanded space. Now, however, they are used intensively and are virtually always driving around. When they are not driving (at night, for example), they are parked on the street, and especially in parking areas situated on the outskirts of the city. Consequently, large amounts of space has been freed up in the city, space that can be used for green areas, kitchen gardens, playgrounds and bicycle paths.

Clean, cleaner, cleanest

Cars are used intensively and drive a substantial number of kilometers per year. Consequently, they depreciate faster and must be replaced. The car fleet is regularly renewed with cars that are replete with *state of the art* technology. The new, cleaner cars have a positive impact on the environment, and moreover they are increasingly lighter. All manner of safety provisions (cage constructions, airbags) are now no longer needed, which drastically reduces the overall weight of the car.

Profiting from mobility

Car manufacturers have radically changed course; they no longer focus on selling as many cars as possible, but rather focus on mobility as a service. The auto industry now primarily earns its money through the offering of mobility. Naturally, there is still a need for cars and small buses, but they are only rarely sold to private individuals. There is a particular need for *people movers*. And auto makers are now doing battle with new competitors, like Apple and Google. Also the occupational structure changes. In the course of time jobs within the car dealer and driving school sectors, and the profession of taxi and truck drivers have been replaced by jobs elsewhere in the economy.
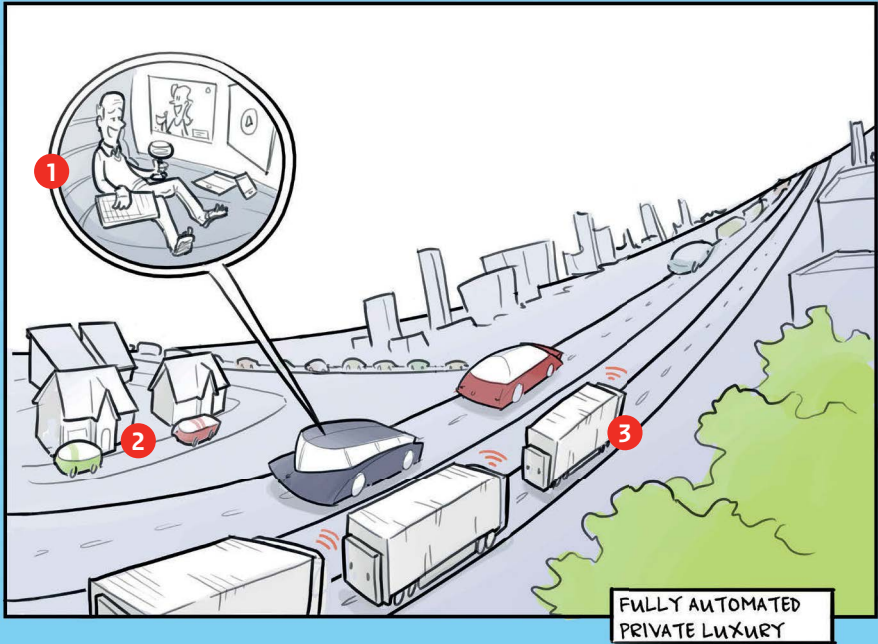
- 'Fully connected' cocoon, without a steering wheel (1)
- Sharing car and rides only within household
- Disappearance of (most) traditional public transportation
- Uber-like system for people without a car
- Cars are parked in front of the door (2)
- People buy cars at car dealers
- Truck platoons on highways; no compartments for drivers (3)

Scenario 2
Fully automated private luxury

In the second scenario, consumers are fervently attached to the ownership of their own cars. The technology in these cars has been developed to the highest level possible.

Fully automated
Google i-Car Special

Jan had always liked cars, but in recent years he has really enjoyed his means of transport. His most recent purchase was a 'Fully automated Google i-Car Special', which nearly caused his neighbors' eyes to pop out of their heads. The car cost a small fortune, but Jan was more than satisfied. He got enormous pleasure from all its technological gadgetry. The dashboard was a huge display on which you could see all the ins and outs of the car. Not only did the car look great, but you could also do everything you could want inside it. In the morning, on the way to the office, you could work on your computer files with ease. Jan also regularly used the car for going on vacation with his wife. They would convert the seats into beds and drive through the night to their destination, with the major difference being that in the past driving through the night meant arriving exhausted. Jan however could not even contemplate sharing this 'technology on wheels' with others. Of course his daughter could use his car, but other people…no. And now he was already dreaming about buying the latest 'Google i-Car Royal de Luxe', which he would soon let take him for a test drive.

General overview

Mine!

Consumers regard the self-driving car as a wonderful invention, so much so that they want the car all to themselves and their families. Naturally, some people are prepared to share their cars with others, but they are a minority. Sharing rides is also met with little enthusiasm, because what is better than driving around without being disturbed by fellow passengers (who play loud music, smell bad, or, perhaps worst of all, want to engage you in 'pleasant' conversation)? The self-driving car is equipped with all the latest gadgetry and is fully customized to the owner's particular desires. As in the past, the car is available in all types, sizes, colors and price classes. The robot car is still parked in front of your home and remains a means of inciting envy among your neighbors. The car remains a status symbol.

Just do what you like

The self-driving car offers new possibilities. After a long day at work, you can drive home 'yourself', have a drink, watch a movie or take a nap. The seats in the cars are easily converted into comfortable beds. At home, your children can track the car's journey and know exactly when mother or father will arrive home (rested).

The robot car is of course also shared, but only within the family and among a small circle of friends. When mother or father arrives at work, the car drives back home and can then be used by other family members.

Other transport modes

Millions of second homes

In the distant past, many people travelled by tram, metro and train, and this meant that you were also driven and delivered to your final destination. And during your trip, you could do something enjoyable or practical. But the car now also offers the few advantages that were once the sole preserve of public transport. The public transport of the past also no longer exists. However, because not everyone can afford a luxurious robot car, a few types of collective transport still exist. Consequently, there are still self-driving minivans driving around, which people can order on demand. Moreover, for travelling longer distances, driverless trains still operate, as well as automated metros that serve the busiest routes in major cities.
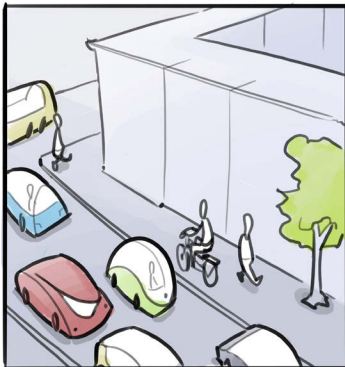
The self-driving car offers great comfort and ease, so much so that we even cycle and walk less. In the robot car, we are dry and comfortable and have all we need at our fingertips. It is a mobile second home, for use both in and outside the city. In the city, car traffic is fully facilitated.
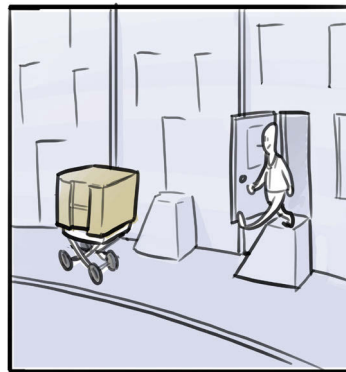
Self-driving packages in freight transport by road

As was the case in the '*Mobility as a service: any time, any place*' scenario, goods are delivered with self-driving trucks or containers. Compartments for drivers are no longer necessary. The goods are delivered to the outskirts of the city, from where they are fully automatedly transferred and delivered.

Societal consequences

'Automated luxury' impacts areas that include road safety, spatial development, the environment and the economy.

Safe in your protective cocoon

Road safety has improved by leaps and bounds and the number of traffic fatalities and injuries among car passengers has plunged to virtually zero. People still make mistakes, but, with regard to traffic, they no longer matter. The technology anticipates all possible traffic situations, is never tired or distracted. Moreover, it is possible to fully protect the technology from hackers and other miscreants.

## Spatial development: car parked in front of your door if possible

Because everyone wants to have such a mobile second home, car ownership rates remain high. This is also due to the fact that senior citizens and invalids can now travel by car. In the distant past, older people, in their 70s and 80s, were often pressured by their children to stop driving, because their reaction times had diminished and they could no longer see so well. However, with the self-driving car, this is no longer an issue. Now, you can keep your car for as long as you like, even if you are 100 years old. Because of such developments, there are now tens of thousands of additional cars on the roads, but cars are also still removed from the overall car fleet. The self-driving car can serve multiple family members.

Consequently, there is less need for a second or third car. However, the demand for parking places remains high and cars continue to occupy large amounts of space. Everyone wants to continue owning cars and have their cars taking pride of place parked outside their homes. In cities, this can lead to parking problems, but they can be prevented by higher parking fees. If necessary, the cars are parked in less expensive areas on the outskirts of the city.
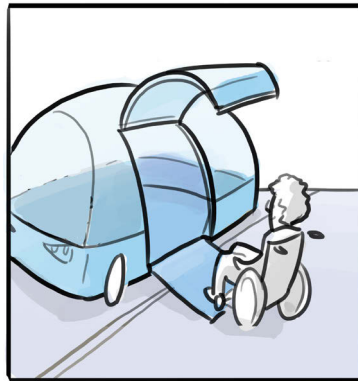
Because it is increasingly easy to travel and people rarely share rides, traffic pressure in the city initially increases. In reaction to this, some businesses leave the inner cities. But everyone can now travel with ease everywhere, and hence businesses (cafés, restaurants en theaters) can also succeed when situated in the remoter areas of the city, where it is also easier for patrons to park their cars. The city continues to attract people as a place to live and work. Within the city, numerous subcenters emerge where people can shop and meet.

Thanks to the self-driving car, the countryside is now more accessible. Owing to the luxury and comfort afforded by your private cocoon, a certain number of people now live in areas that were previously not an option. This has revitalized the countryside. The small group of residents who do not own cars use the self-driving shared cars, which are to a limited extent available in smaller residential communities.
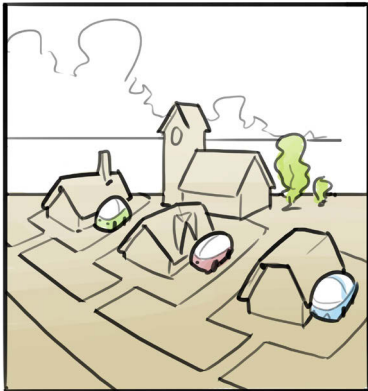

A kilometer more or less, who cares?

The environment is not really benefiting, because, firstly, the robot car is such an attractive transport mode that more kilometers are being driven. You no longer need to leave your car at home when going out to a bar or club. Senior citizens may perhaps faintly recall some of the government's old 'anti-drink& drive' campaigns, but with the advent of the robot car such campaigns are relics of the past. After a night out on the town, you can get into your car with a clear conscience: you may be impaired by alcohol, but your car is not. Secondly, the robot car is not being optimally utilized. When mother and father have arrived at work, the car drives itself home, where it can be used by other family members

But these are in fact 'useless kilometers', because during the return journey home the car is empty. Fortunately, there is a counterbalance: because these cars are so convenient, they are used intensively. No one cares about a kilometer more or less; hence, the cars are sooner replaced, with cleaner and more innovative cars being purchased to take their place, even though this occurs more slowly than if the cars were being intensively shared. There is moreover an additional benefit: the car's weight can be reduced. These cars are extremely safe, hence various safety features, like heavy cage constructions and airbags, are no longer necessary. However, conversely, all the various luxury extras do make the cars heavier. Although not everyone can afford such extras, these extras, which

include 3D screens, refrigerators, espresso machines and like, do perfectly suit a second home.

Profiting from the self-driving car

The car industry is flourishing. Households want to own their own cars. While there is perhaps now less of a need to own second or third cars, the first car is more quickly replaced. All is well with the auto industry, but the competition is fierce. New players, like Google and Apple, have also entered the car market. In order to stay a step ahead of the competition, auto makers are developing all types of models, including luxury status symbols, which have large profit margins. Car dealers remain important: there are still showrooms full of glimmering robot cars, but of course one can also view such cars online. And whoever wishes to take a test drive is picked up at home by the car of their choice.

LETTING GO
ON HIGHWAYS
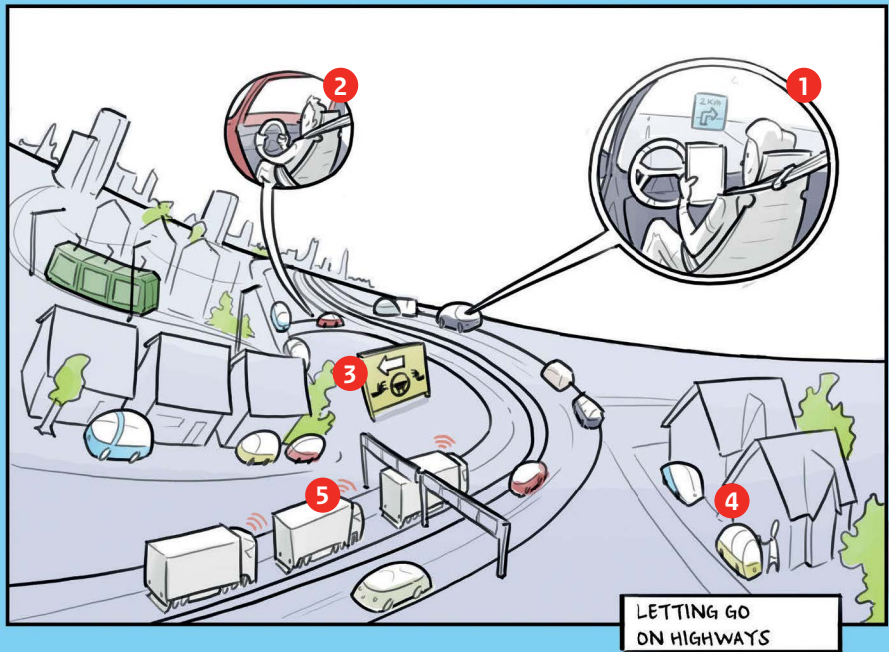
- 'No hands' on highways (Level 3/4) for many **(1)**
- 'Hand on steering wheel' within the city,
  but driver assistance systems available (Level 1) **(2)**
- 'Transition zone' necessary from highway to city **(3)**
- Automated parking within parking garages
- Cars are parked in front of the door **(4)**
- Truck platoons on highways; drivers can rest **(5)**

Scenario 3
Letting go on highways

In the third scenario, the technology is less developed. In the congested, chaotic cities, car drivers must still drive themselves. A minority of drivers are prepared to share a car. The majority opts to own their own cars.

Difficulty letting go

Martje was happy with her new car. It was the fifth car she'd ever owned, and she had seen her cars change step by step over time. Not much had changed about the exterior, but the cars were becoming increasingly sophisticated. Not that all the technological developments interested her that much, but she did find it important that the cars were becoming increasingly safe. She liked the idea that the technology was also now keeping an eye on things. Thanks to the latest gadgetry, she could let go of the wheel on the highway. She preferred not to do this, however, but her husband liked to do so. He would close his eyes and let the car drive him restfully into the city. Martje would not this, though. For her entire life she had been the boss of her car and had no intention of now becoming some passive princess, driving around waving to the other drivers.

Martje was attached to her car. She liked the few shared cars she'd seen parked in her street, but that was nothing for her. She could easily pay for her own car, and ordering a shared car would be a hassle. Moreover, she didn't even want to think about sitting in an interior that other people had made dirty. She couldn't imagine what you might find in such cars.

General overview

Letting go on the highways

Many people are expectedly waiting for the advent of the self-driving car. These high expectations however are only partially satisfied. Many people are not yet open to the self-driving car: they find it horrible to succumb to technology in this way. Is the technology 100% trustworthy? After all, we do not yet fly on planes that have no pilots? And such concerns are not wholly unfounded. Newly developed and safely-compiled systems proved initially capable of being 'hacked'. Recent technological improvements have however severely minimized such risks and people's trust in such systems has increased, yet this does not apply to all people. Moreover, many people simply enjoy steering with their own hands. The consumers' limited acceptance and interest has therefore ensured that the car industry has somewhat reluctantly invested in automation and further technological developments. Did they satisfactorily present the concept of the fully autonomous cars to the people? Moreover, other problems have emerged, such as autonomous maneuvering in congested city traffic, which have proved more difficult to solve than expected. Human driving remains, and therefore remains necessary in many cases.

A relatively high degree of automation has been achieved on national and provincial roads, as facilitated by the government. There, drivers can lean back and relax and let go of the wheel. However, a significant minority of car drivers prefer to keep hold of the steering wheel with their own hands, proving that the self-driver is in fact a cautious person.

Retained in the city

In the congested city, all hands remain on deck. Here, car drivers must drive themselves, but they do receive all types of supporting information. They are warned when obstacles are approaching and receive signals when other cars, cyclists or pedestrians are in close proximity. If an accident seems imminent, the car executes an emergency stop, for example. Parking is no longer a problem, as the car parks itself. In well-organized locations, such as parking garages, you can also exit your car at the entrance and the car – supported by real-time parking information – will find a parking place itself.

Shared cars are driving around, but car sharing has not been a great success. The vast majority of people remain attached to their own cars. The ease associated with owning a car – the car is always ready and waiting for you – is unassailable. Moreover, it remains a means of self-expression: the car reveals who you are and what you have achieved in life.

Other transport modes

Public transport and cycling: little new under the sun

In the city, we still find the old, trusted forms of public transport. Trams and metros continue to fulfill important functions. But here, too, there are technological developments: metros, and most trams, no longer require drivers, as they travel on open lanes. Buses are present to a limited extent. They still have drivers, but they can let go of the steering wheel on the highway. In the city, bus drivers have driving support systems. The self-driving car has had little impact on slow traffic. The role of the bicycle has hardly changed. In the city, car traffic is fully facilitated.
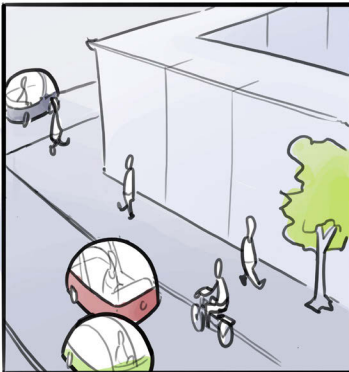
'Trains' of trucks

On the highways, one is confronted by 'trains' of trucks. While the drivers rest, their trucks drive 'connected', according to their destinations, and they can also perform other limited functions. The trucks drive close to one another and thus occupy less space on the highway. As with private cars, drivers take over control when entering urban areas.

Societal consequences

Cars are shared relatively infrequently and the technology in cars is not impressively developed, which has consequences for safety, social cohesion, spatial development, the environment and the economy.

Improved road safety

Even though a fully self-driving car is not yet available, the associated technology still makes an important contribution to improving road safety. Road safety has particularly improved outside of urban areas, where human error is sooner eliminated. Within cities, support systems, such as emergency braking systems, help to prevent many accidents. However, the technology, and the trust in it, is still not so highly developed that cage constructions, airbags and seatbelts have been rendered obsolete.

Spatial development: transition zones

The attraction of the city continues unabated, with young people especially finding all they need there. But parking remains a problem, because everyone still wants to own a car. Even digital parking assistants that quickly find parking places are of little help. Cars have a major impact on the available space. Cities are an ideal place to live, but because driving on the highway has now become so much easier, many city dwellers routinely leave the city for recreational purposes. Moreover, it is now easier to find work in another city, because the commute to these cities is so much easier.

The space on the outskirts of the city is organized differently: here are the transition zones, in which car drivers are given the space to easily switch from driving the car themselves to automated driving, and vice versa. Car drivers who reach the city limits

receive a warning signal (sounds and vibrations in their seats), informing them that they must now take over control of the car. If drivers fail to respond to this signal, because for example they are deeply asleep, the car will park itself in a space in the transition zone.

The pace of change is limited outside of the city and in the countryside. Some rural areas have become even more depopulated. The remaining residents usually own a car. Residents who do not own cars can use buses. On the busier routes, they travel according to a timetable. In sparsely populated areas, buses follow alternate routes that are dependent on demand. Supply and demand are aligned through real-time information.

The environment and economy: many stick to the old ways

Today's cars still look a lot like the cars of old. They are safer, and still have safety features like cage constructions and airbags. The car's weight has therefore not decreased, and consequently the environmental benefits are limited. The car industry continues on its old path and still produces many 'traditional' cars, even though it is necessary to profit from the supporting technology. Because many car drivers have reacted reservedly to the self-driving car, there is little investment in the further development of the technology.

MULTIMODAL AND SHARED AUTOMATION
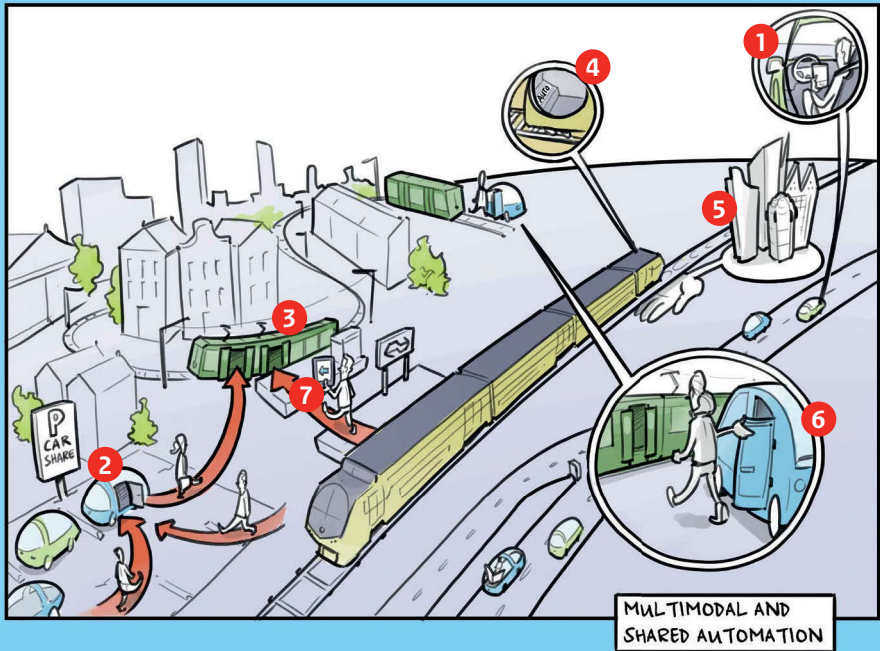
- 'No hands' on highways (Level 3/4) for many **(1)**
- High level of sharing (car ownership and rides) **(2)**
- Public transport is popular because of a preference for sharing **(3)**
- Trains/trams/metros without a driver and a high frequency of travel **(4)**
- Government encourages large-scale public transport in the city **(5)**
- Efficient multimodal trips and transfers **(6)**
- Digital travel assistant arranges the journey **(7)**

Scenario 4
Multimodal and shared automation

In the fourth scenario, sharing a car is the most natural thing in the world to do. Fully automated driving is not yet feasible, the technology is not yet sufficiently developed, and support is limited.

Shared cars in abundance

*P*auline was one of the first to engage in the sharing economy. In the beginning, people looked at her strangely when she shared her drill, house and car with others. But sharing soon became the new normal. She could now choose from eight shared cars parked on her street, for example. Some of the cars were offered by organizations, and some by her neighbors. She regularly hired a car and routinely shared rides. She got rid of her own car. She also received permission to start a community garden in her old parking place, which added more greenery to the neighborhood. She didn't need to use a shared car very often. Pauline travelled a lot by bike and she enjoyed that; it made her feel fit, and moreover she needn't worry about polluting the environment. She also didn't need to use a shared car very often, because on the next street a superefficient tram stopped every three minutes, offering connections to metro and train lines.

General overview

Limited trust in and acceptance of technology

In the *'Multimodal and shared automation'* scenario, technology and acceptance encounter obstacles, as was the case in the *'Letting go on highways'* scenario. The technology can take over control of the car from the driver on national and provincial highways, but this remains a bridge too far in the congested cities.

People embrace sharing

Car drivers are however convinced of the value and utility of car sharing, which in turn is part of a broader social development: the sharing economy is flourishing. Sharing goods and services with others is now the most normal thing in the world to do. It makes money and renders society a bit more livable and sustainable. Hence, every street has a number of shared cars. Some are offered via organizations, but joint car sharing (neighbors among themselves) is also flourishing. Sometimes you travel alone in such cars, sometimes with others (rides are also shared), and sometimes a taxi driver – supported by technology – picks up various people who are all travelling in the same direction. Those who want to leave the city can also be brought to the train station.

Other transport modes

Everyone holds each transport mode equally dear

Automation is having an impact on public transport in particular. Buses are present to a limited extent and still have drivers. Trains, trams and metros travel along separate routes without machinists or drivers. Thanks to information and communication technology, and the lower costs derived from the fact that drivers are no longer required, a higher frequency of travel on public transport routes is now possible. Consequently, many people are now interested in using public transportation, which – especially in cities – has become a major competitor of shared cars. In addition, ICT support has optimized travel: everyone now has a digital travel assistant that makes transfers incredibly easy. Due to the high frequency of public transport, waiting is a thing of the past. One effortlessly switches from train to tram, from bike to metro.
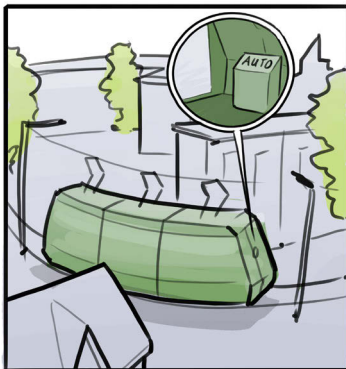
Skepticism about public transport is increasingly declining. People simply opt for the most efficient transport mode, whether that is bicycles, shared cars or the metro.

Healthy transport modes and multimodal trips

The focus on liveability and sustainability is coupled with a preference for leading a healthy lifestyle. In the city, many people walk or travel by bicycle (and when the travel assistant recommends it: they occasionally travel a stretch via public transport). Outside of cities, many stick to the old ways: the (driverless) train remains an important link between cites.

'Trains' of trucks

Technology has developed to such a point that driverless trucks drive 'connected' to each other on the highways. The trucks travel close to one other and therefore occupy less space. When the city limits are reached, the driver once again takes control of the steering wheel.
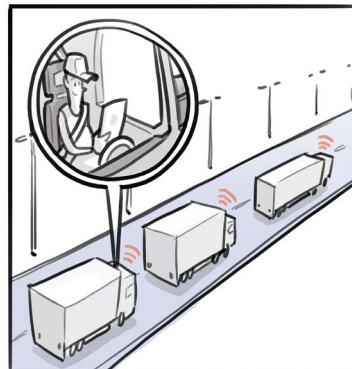
Societal consequences

Sharing cars and trips and the (limited) development of technology has various societal consequences.

Increased road safety through intensive use of public transport

Road safety has improved. This is partly due to the supporting warning systems in cars, but also due to the intensive use of public transport. Those who travel in an automated metro – and there are many who do – cannot cause accidents.
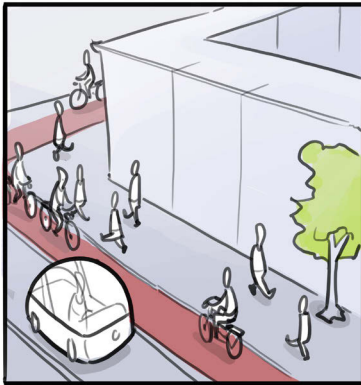

Spatial development: fewer cars, more green spaces

Because sharing cars and rides is such a success, fewer cars are needed. The former parking lots are now used for bicycle stalls or green areas and some streets have been transformed into bicycle paths where the car is 'the guest'. The cars that remain are still parked in front of homes. There are no large parking areas situated on the outskirts of the city, the cars in the city still require drivers and cannot be autonomously driven to one's door. Those who have a (shared) car keep it parked in the neighborhood out of necessity.

Sharing also occurs in rural areas. The larger car fleet companies put shared cars in places where it is profitable to do so. Moreover, sharing occurs between neighbors ('peer-to-peer'). On busier routes, buses operate according to timetables. In quieter areas, buses follow routes that change according to the real-time travel requests received via ICT systems. These buses can be operated both by municipalities and local collectives or cooperatives.
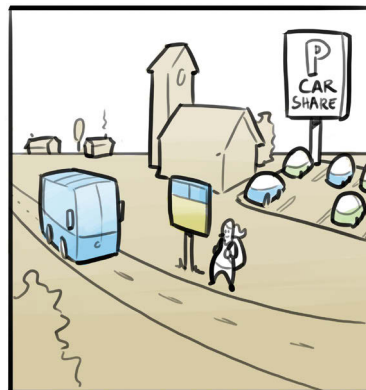
Continuously the newest of the newest

Because of the intensive manner in which they are used, shared cars are frequently replaced, which is also beneficial for the environment, as the latest model cars are always a step more advanced and cleaner. Further, not much has changed in terms of the car's construction: safety features, such as cage constructions and airbags, are still needed.

Profiting from mobility as a service

Car manufacturers foresaw that fewer cars would be sold and have therefore entered into the sharing economy. Cars and buses are still sold, but greater profits are earned from selling mobility services.

Differences between scenarios and intersections with policy

This study presents four scenarios for a future traffic and transport system involving self-driving vehicles. These scenarios help analysts and policymakers to envision future developments, to identify uncertainties, and to consider the associated advantages and disadvantages. The scenarios have varying implications. While some developments perhaps still seem a long way off in the future, they do however intersect with choices that are made today but will have consequences later, such as long-term investments in (rail) roads and the physical environment. We therefore conclude with an overview of a number of key differences between the four outlined scenarios and the questions they raise. Additionally, we also discuss the intersections with policy. We begin with the impact that self-driving cars have on road capacity and car traffic volumes. We then describe the implications for public transportation, bicycles and freight transport. We also examine the wider societal consequences for spatial development, social inclusion, (traffic)safety, the environment and the economy. The table on page 36 provides a first indication of effects.

Road capacity and traffic management

Self-driving vehicles can quickly react to changing situations. They can travel closer to one another, which substantially increases the road capacity. To achieve this, it is crucial for self-driving vehicles to be able to exchange information with each other, via *cooperative systems*, whereby it then becomes possible to prevent sudden braking and unexpected lane changes, for example. This allows for a calmer traffic environment, whereby road capacity is further increased, although such a scenario is

highly dependent on how many vehicles on the road are in fact self-driving (the 'degree of penetration'). If vehicles do not contain cooperative systems, road capacity could also decrease, because drivers would have to maintain longer following distances than at present.

In each of the four scenarios, the road capacity therefore is expected to increase. There are however differences in the extent of the capacity gains and in the types of roads where this occurs. In the '*Letting go on highways'* and '*Multimodal and shared automation*' scenarios, the capacity gains primarily occur on highways. In the other scenarios, this also occurs on other roads. Consequently, the development of a transport system involving self-driving cars intersects with questions and uncertainties pertaining to investments. If many self-driving cars emerge, will there then be overcapacity on the roads, and where will this occur? Only on highways or also in the city?

Concurrently, the demand for mobility may also further increase. Does this mean that the capacity requirements will perhaps also increase on highways and on the transition of highway to city? And what does this mean for investments in infrastructure? Does the government retain a role in traffic management and information provision? Are physical roadside systems and traffic control systems still needed? Can the market take over this function? How does this relate to privacy issues and laws and the ownership of data? And, crucially: how do we ensure that these types of systems are also capable of communicating with each other on the international level?

Table: First indication of effects from self-driving cars

	Mobility as a service: any time, any place	Automated private luxury	Letting go on highways	Multimodal and shared automation
ROAD CAPACITY AND VOLUME OF CAR TRAFFIC				
Capacity	+	+	o/+	o/+
Volume of car traffic	+	++	o/+	o
OTHER TRANSPORT MODES				
Public transportation	- -	- -	o	o/+
Bicycle use	o/+	-	o	+
Automated freight transport	++	++	+	+
WIDER SOCIETAL CONSEQUENCES				
Number of parking places	- -	o	o	-
Spatial distribution	+	++	o	o/-
Social inclusion	++	+	o	o
Traffic safety	++	++	+	+
Environment and livability	+	-	o/-	o/+
Auto makers market	-	+	o	- -
Number of car dealerships	- -	o	o	- -
Drivers (public transport and freight transport)	- -	- -	o	o

++   large increase

+   increase

o/+   small increase

o   no increase or decrease

o/-   small decrease

-   decrease

- -   large decrease

Volume of car traffic

Self-driving cars can result in increased mobility, and hence also in a greater demand for mobility. The extent of that extra demand primarily depends on which tasks the self-driving cars can ultimately assume, on which types of roads this can occur, and on the extent to which people are also prepared to relinquish control of their steering wheels.

The number of vehicle kilometers substantially differs per scenario: from an expected limited increase in the '*Letting go on highways*' and '*Multimodal and shared automation*' scenarios, to strong growth in the other two scenarios. But how large is this increase? And what does this mean for traffic jams and congestion? Does it increase or decrease? Increased congestion is unlikely in the '*Mobility as a service: any time, any place*' scenario, because the market ensures that there is a place- and time-dependent pricing of mobility. If demand increases, the price of mobility services increases, whereby the demand for mobility and the road capacity remain in balance. However, this pricing mechanism does not occur in the '*Fully automated private luxury*' scenario, because in this scenario there are no large car fleet companies offering mobility services. In that scenario, traffic congestion is likely to be regarded in a very different manner: if you are able to work or watch a movie in your car, then how unpleasant can it be to be stuck in traffic? These are questions that intersect with discussions about the necessary investments in roads, as well as with issues pertaining to the environment and livability of cities.

Public transportation and bicycle use

The development of self-driving technology is not limited to cars only. It can have an impact on the entire transportation system, and thus also on public transportation, bicycle use, and pedestrians. Public transportation occupies a clearly distinct position in each of the four scenarios, ranging from growth in the '*Multimodal and shared automation*' scenario and limited changes in the '*Letting go on highways*' scenario, to the complete disappearance of traditional public transportation in the other two scenarios, except for a few remaining train services. Also the position of the bicycle and pedestrians in the transport system differs in the scenarios.

These differences intersect with questions pertaining to possible policy and investment choices in the short and medium terms. In what form will public transportation still exist? What does this mean for decisions about long term investment in public transportation? How flexible must concession grants be? Does public transportation primarily remain a public service or does the private sector play a more important role? Are self-driving cars welcome in the cities, or is the preference for a car-less city with plenty of space for bicycles and pedestrians? Or will it be some combination thereof?

Freight transport by road

Self-driving technology may also have an impact on freight transport by road. In the two scenarios in which trucks drive fully automatedly – '*Mobility as a service: any time, any place*' and '*Fully automated private luxury*' – transportation to the front door also occurs fully automatedly. If small goods, such as packages, can be automatedly delivered to customers, this will have consequences for the distribution of goods. Are there freight distribution hubs and transfer

centers situated on the outskirts of the city, so that large freight loads no longer need to enter the city? And what are the spatial consequences? Will local distribution centers be established in neighborhoods? Are packages automatedly driven directly to the customer, and are they sufficiently secured? And how livable is a city in which all these small or bundled packages are being driven around?

If the technology remains less developed, can a situation exist with only self-driving trucks operating outside of urban areas, as in the '*Letting go on highways*' and '*Multimodal and shared automation*' scenarios? This intersects with the questions pertaining to safety and spatial planning. Can these 'trains' of trucks travelling closely behind one another actually drive on highways with other vehicles? Or, for example, are separate target group lanes needed during a transition period?

Parking

Information technology ensures that it is easy to find parking places in all scenarios. When arriving at an empty parking place, the vehicle parks itself. There are however also key differences. In the scenarios in which car sharing has not taken flight, people prefer to park their private cars in front of their homes. The parking pressure therefore persists. If a car can drive automatedly everywhere and at all times, and self-driving cars are shared, as in the '*Mobility as a service: any time, any place*' scenario, then far fewer cars will be needed to satisfy the mobility demand. Additionally, when cars are not in use, they will be parked on the outskirts of the city. Individual car ownership also sharply decreases in the '*Multimodal and shared automation*' scenario. This has clear consequences for parking and car

ownership, and hence also for spatial planning and fiscal policies. For example, to what extent will governments promote car sharing by instituting parking fees in inner cities? Will substantial numbers of cars disappear from our streets? What does this mean for parking and spatial use? And for taxation, such as road taxes and private motor vehicle taxes?

Spatial development

Self-driving vehicles can lead to changes in land use, spatial planning and spatial design. This is due to the fact that people will make other choices with regard to where they want to and can pursue certain activities. Hence, there is for example a relationship between the distance of a trip and parking (see above). In the long term, self-driving vehicles can also influence the spatial planning of the city and environs, and vice versa.

The impact of the self-driving car intersects with questions pertaining to the future development of cities, the role of hub/nodal development, and livability. Consequently, the livability of peripheral areas can increase, because people with self-driving cars can more easily travel longer distances and hence more people will move to rural areas. The livability increases even more if certain social groups – such as children, seniors and the disabled – are able to travel more easily by car, as in the '*Mobility as a service: any time, any place*' and '*Fully automated private luxury*' scenarios. In addition, the self-driving car partially intersects with investments in the road system. Are, for example, transition lanes or zones needed if the car cannot automatedly drive everywhere, such as in the '*Letting go on highways*' and '*Multimodal and shared automation*' scenarios? And what must this entail?

Social inclusion

Self-driving vehicles can facilitate travel, and this not only applies to the traditional groups of car drivers. Self-driving cars can also engage new groups of travelers, but the extent to which this will occur is highly dependent on the extent to which automation is further developed. Trust in technology plays a role here: will parents for example dare to allow their children to travel in these fully automated cars, such as is the case in the '*Mobility as a service: any time, any place*' and '*Fully automated private luxury*' scenarios? And who then is responsible if an accident occurs? Affordability can also be an issue. If a car is able to drive perfectly on its own, but the service is too expensive for some groups of people, then social inclusion does not increase. And with this comes the issue of social equality. To what extent do we want everyone to be mobile? What could and will this cost? And how could these costs ultimately be reimbursed? Could this be done via a personal mobility budget? Or are there other, more efficient and effective methods?

(Traffic)safety

Self-driving vehicles have a major effect on traffic safety and therefore also on policy. In the most far-reaching developments, accidents involving vehicles have largely been relegated to the past. Here, however, it is vital for the technology to be fully protected from hackers and other miscreants. Whether this is possible is currently unclear.

An additional challenge is the interaction between vehicles and slower traffic in cities. Cyclists and pedestrians make their own decisions in daily traffic. But can this system function properly with so many self-driving vehicles in the city, as in the '*Mobility as a service: any time, any place*' and '*Fully automated private luxury*' scenarios'? This intersects with the questions pertaining to safety and the design of cities. Should there be a clear distinction made between self-driving vehicles on the one hand, and cyclists and pedestrians on the other? Or can the traffic be easily mixed without any ensuing problems? And if it proves impossible to fully guarantee security, then an ethical and legal discussion ensues about which risks are acceptable and who is liable if an accident occurs. What must a self-driving car do in the rare situation that an accident is difficult to avoid? Does the car for example opt to run over the cyclist or at the last moment to diverge and drive into a tree instead? And who determines what choice the car must make?

Traffic safety also plays a role when the technology is less advanced and people in some situations must take control of the steering wheel themselves, such as in the '*Letting go on highways*' and '*Multimodal and shared automation*' scenarios. It is time-consuming to switch from automated to manual driving. How fast can people do this and to what extent does this depend on the situation and the activity that a person is engaged in at that moment? And must there be certain provisions, such as transition lanes, established in order to facilitate these transfers?

Environment, livability and health

Self-driving vehicles can have an impact on the environment, depending on the degree of automation, the popularity of the sharing economy, and the mobility volume.

Self-driving cars can have positive effects on the environment and human health, but the exact effects are difficult to determine. If the sharing

economy takes flight, as in the *'Multimodal and shared automation'* and *'Mobility as a service: any time, any place'* scenarios, this would be beneficial for the environment. But will sharing become the new norm? And will the ease associated with self-driving cars result in more car trips and thus more pollution? Or is this in fact advantageous, since cars will then be more quickly replaced by new models and innovations will find their way to market more quickly?

Economy and employment
Self-driving vehicles can impact many facets of the economy. The effects are complex and difficult to determine, however. To what extent will jobs within the traffic and transport sector change or disappear in the course of time? And to what extent will further automation result in jobs losses at freight handling and distribution centers? At the same time, new employment opportunities could also emerge. But what types of jobs would they be? Do new companies emerge offering mobility services? And what could the government's role in this be? Will more jobs be created due to the need to develop hardware for self-driving cars, such as manufacturing chips and sensors? And what about on the software side? Here, for example, a demand could arise for new systems, such as digital travel assistants, which organize and optimize trips for travelers.

Conclusion: transitions and challenges for policy and knowledge development
The four scenarios presented in this study are intended to serve as sources of inspiration, helping in the process of contemplating the consequences of self-driving vehicles. What will a world full of 'robot cars' look like? Will a self-driving shared car possibly emerge?

The social impact of such a development could be great. However, these developments are still seemingly distant and uncertain, yet they do intersect with policy choices in the here and now. The scenarios offer policymakers a starting point for intensively thinking about the possible advantages and disadvantages of such future developments.

There are also many challenges facing knowledge organizations. Consequently, there is work to be done to further substantiate the traffic and transport effects and the broader social implications of self-driving vehicles. In addition, there are many uncertainties and developments in the short and medium term that will ultimately determine what future traffic and transport systems actually look like. Herein it is important what people want and do, how self-driving carmakers can and will produce these cars, and the extent to which the government facilitates and regulates developments. And these pertinent points are all interrelated. Will people want to ride in self-driving cars? How will information and data be owned, used and shared? To what extent will people want to share cars? And are automakers capable of developing cars that can automatedly drive everywhere and always safely? In order to gain a deeper understanding of potential eventualities, a following step could be to outline the possible paths of transition, which could also serve to further define the policy issues.

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